REPORT NO. 65-54
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Semi-Annual Status Report for the Period

June 1, 1965 – November 30, 1965

AN INVESTIGATION OF CERAMICS AS STRUCTURAL MATERIALS

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AN INVESTIGATION OF CERAMICS AS STRUCTURAL MATERIALS

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FOREWORD

The research described in this report, "Semi-Annual Status Report for the period June 1, 1965-November 30, 1965, on An Investigation of Ceramics as Structural Materials," was carried out under the technical direction of F. R. Shanley and W. J. Knapp, and is part of the continuing program in Analytical and Experimental Investigations of Ceramic Materials for Use as Structural Elements.

This study is conducted under the sponsorship of the National Aeronautics and Space Administration, office of Space Sciences, Washington, D. C.

Submitted under Contract No. NsG-427.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. George Kendall of the Materials Science Laboratory, Aerospace Corporation, El Segundo, California, for loaning us a fixture for uniaxial prestressing.

The interest and assistance of the International Pipe and Ceramics Corporation, Los Angeles, in fabricating and donating ceramic plates for this research, are gratefully acknowledged. Earlier support also was provided by Interpace (then Gladding McBean and Company) for the study of a biaxially prestressed ceramic slab.

The contributions of David Weiss, George Nikolaychik and A. P. Raju, as former members of the project staff, are gratefully acknowledged.

I. INTRODUCTION

This research program is directed towards the successful utilization of ceramic materials in structural applications. Current progress of the following investigations, based on previous experience, are reported herein:

1. Effects of directional cellulation on the strength of a ceramic material
2. Strength of some ceramics containing hollow glass spheres
3. Bending-stiffness properties of a prestressed segmented ceramic plate (composed of square segments)
4. Fabrication and testing of a prestressed ceramic plate comprised of triangular segments
5. Fabrication and testing of ceramic domes
6. Behavior of biaxially prestressed ceramic plates subjected to thermal stresses
7. Load bearing characteristics of uniaxially prestressed ceramic beams.

II. STATUS OF INVESTIGATIONS IN PROGRESS

1. Effects of Directional Cellulation on the Strength of a Ceramic Material

The effect upon strength of controlled porosity was quantitatively determined for ceramic specimens containing parallel cylindrical cellulations. These specimens were loaded to failure with compressive loading being in the axial direction of the cellulations. Strength/weight characteristics were greatly improved when compared with such characteristics for ceramics containing uncontrolled porosity.

A paper based upon this work has been written, and copies will be transmitted at an early date to NASA.

2. Strength of Some Ceramics Containing Hollow Glass Spheres

This research is concerned with the strength of ceramic specimens made by incorporating thin-walled silica glass spheres (see Figure 1) in a glassy matrix. These spheres produce a pore structure which should give a light-weight ceramic prossessing improved strength.

In these tests the glassy matrix component used was powdered glass of a commercially-available soda-lime type (screened to give particles below 200 mesh). Mixtures of these hollow spheres, powdered glass, and a small amount of organic binder, were prepared. The experimental mixtures were dried in an oven, hand-crushed and screened through a 60 mesh sieve. The sieved mixture was charged into a mold and cold pressed, using a forming pressure of 2000 psi, to form beam-specimens about 1/4" x 3/8" x 3-1/2" in size. The specimens then were sintered; after sintering, they were tested for their mechanical strength in bending.

Experimentation is continuing and several additional matrix components are being investigated. They include an epoxy-plastic, and white Portland cement. It appears desirable to use several matrix components to confirm the effect of the hollow spheres. Preliminary results indicate that the strength characteristics of these specimens are good considering their pore contents.

3. Bending-Stiffness Properties of A Prestressed Segmented Ceramic Plate (Composed of Square Segments)

A report (UCLA No. 65-26, June 1965), has been prepared and submitted. This report summarizes the results of an experimental investigation of the structural characteristics of a prestressed segmented ceramic plate. The plate was composed of one-inch-thick square ceramic blocks that were held together by steel wire-ropes. The structural properties of interest were the bending, twisting, and Poisson stiffnesses.

The experimentation involved two cylindrical bending tests for the determination of the flexural stiffnesses D_x and D_y, an anticlastic bending test to find the Poisson stiffness D_1 and two twisting tests to determine the twisting stiffness D_{xy}. The experimental results were as follows: D_x was 28,550 lb-in ^{2}/in., D_y was 13,450 lb-in. ^{2}/in., and D_{xy} was 62,000 lb-in. ^{2}/in. on the average. D_1 was very small, being 305 lb-in. ^{2}/in. These stiffnesses were different at various plate locations because of non-uniformities of the plate prestress.

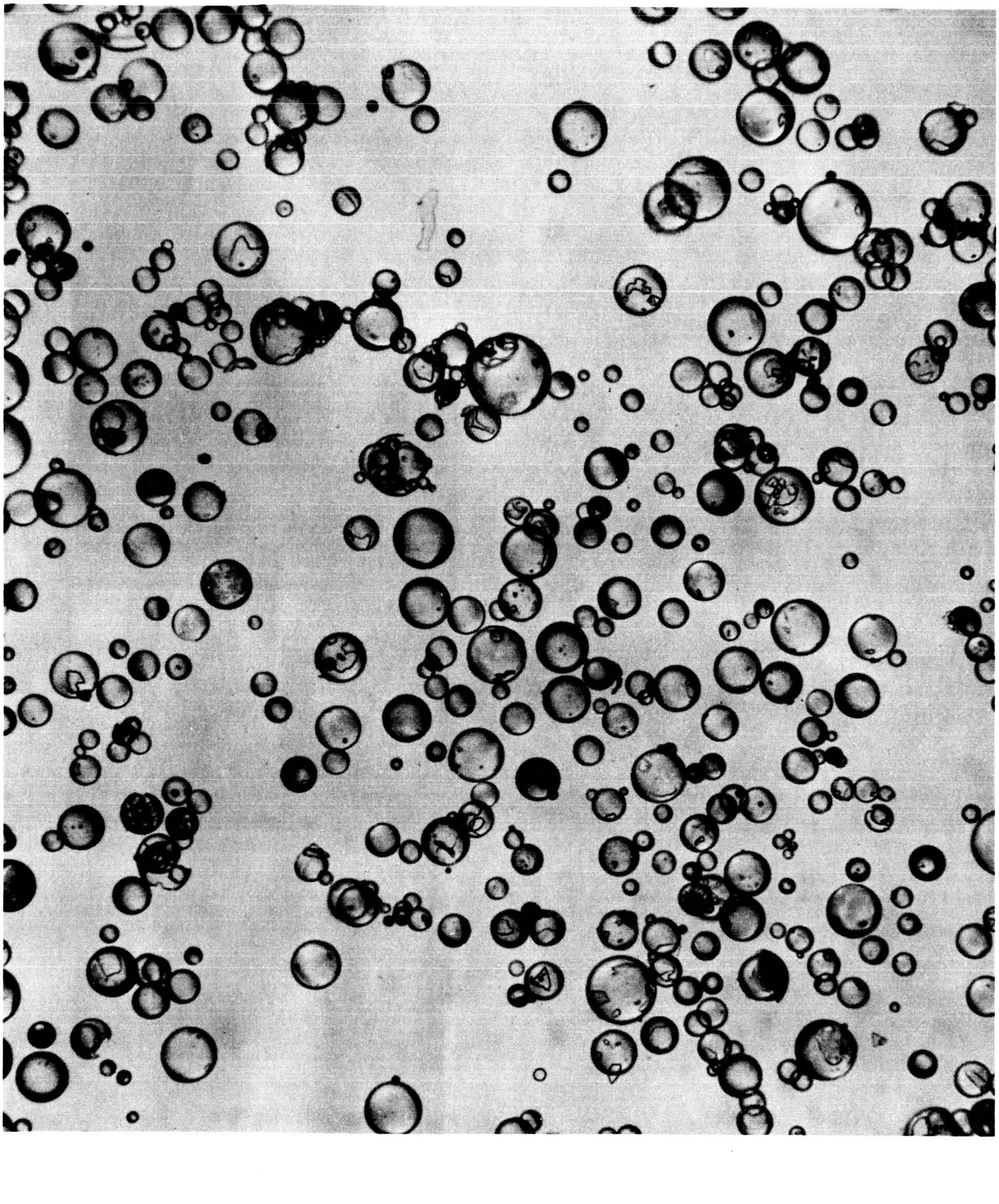

Figure 1

Photomicrograph of Thin-walled Silica Glass Spheres
(Diameters Range from About 30 to 300 Microns)

The stiffness constants D_x, D_y, D_{xy}, and D_1 also were derived analytically from the geometries of the cross section and an effective elastic modulus E and an effective Poisson ratio μ of the composite plate. The flexural stiffnesses D_x and D_y were calculated to be 37,300 lb-in ^{2}/in., and 13,300 lb-in. ^{2}/in., respectively, whereas D_{xy} was calculated to be 156,000 lb-in. ^{2}/in. The Poisson stiffness D_1 was calculated to be 5,560 lb-in. ^{2}/in. The agreement between the experimental and analytical stiffnesses is considered to be good in view of the assumptions involved in the calculations.

4. Fabrication and Testing of Segmented Ceramic Plate Composed of Triangular Ceramic Segments

This work involves the fabrication of a segmented ceramic plate using triangular ceramic segments. An analytical and experimental study of the structural characteristics of the three-way-prestressed plate will be made. The prestressed plate will be composed of 1,421 separate triangular segments of 2" in edge length and 1-1/4" thick. Current work is concerned with the fabrication of segments by slip-casting using an alumina-feldspar-clay body. The cast segments are fired in an electric kiln to about 2,300°F.

Fabrication of the triangular pieces is about 65% complete. Further progress will be reported subsequently.

5. Fabrication and Testing of Ceramic Domes

The objective of this work is the fabrication of prestressed ceramic elements with double curvature, with particular emphasis on the utilization of such elements as building units for larger structures.

A hemispherical dome about 18 inches in diameter was chosen as a structure to be fabricated with ceramic units having double curvature.

The successful fabrication of segmented ceramic domes in the university laboratory has proved to be a difficult task in view of the limited facilities and lack of skilled ceramic technicians. However, considerable experience has been attained in this work, and the following summary may be helpful in designing and fabricating future segmented structures with double curvature.

a. Fabrication and testing of single-piece (monolithic) ceramic domes

It was considered desirable to fabricate and test several single-piece ceramic domes, inasmuch as the results would be useful for comparison with those to be obtained with prestressed segmented domes. The slip-casting process was chosen for fabrication; suitable plaster-of-Paris molds were designed and fabricated by a commercial mold shop. An alumina-containing ceramic body (50% alumina, 20% feldspar, and 30% clay, by weight) was prepared in slip form (dispersed with sodium silicate), and about five hemispherical domes were successfully formed and fired. After firing, these domes were about 17 inches in outside diameter and approximately 1/2 inch thick.

Some local interest was expressed in testing such a dome hydrostatically. With the approval of NASA, two domes were provided to the U. S. Naval Ordnance Test Station, Pasadena, California, for hydrostatic testing.

Before testing, each dome was sealed by inverting it onto a metal plate and evacuating the air from the dome through a hole in the plate. This vacuum was sufficient to hold the dome onto the plate when the assembly was placed under water and subjected to buoyancy forces. External hydrostatic pressure was then applied to the dome at a rate of 130 psi/minute until the maximum of 1200 psi (machine capacity) was reached; after remaining at 1200 psi for one hour, the pressure was released at the same rate. Failure of the ceramic did not occur at any time. Strain-gauges were attached to the dome surface to permit an evaluation of deformations.

Although the first test demonstrated that the domes could withstand the pressure to which they were subjected, it was noted that the porosity of the ceramic enabled water to enter the dome. In subsequent tests, the domes were externally coated with an epoxy film, and water seepage did not reappear.

The complete results of the above testing, and the use of such information in the design of underwater structures, are given in a thesis by S. H. Brand.[1]

b. Fabrication of prestressed segmented domes

Two steps were involved in this fabrication: firstly, the design of segments to be used for generating a dome, and secondly, a forming procedure for making ceramic segments.

1. Design of Segments

It was felt that segments of triangular shape are particularly well-suited for generating members with double curvature. The first design was of a hemispherical dome that could be fabricated by assembling 12 segments of equal size and shape. It is considered that this segment design is unique, in that it allows for the generation of the dome with the assembling of segments of a single type. The shape of this segment is shown in Figure 2. It may be seen that a hemispherical dome may be fabricated by assembling 12 segments (Figure 3). Each segment contained two holes for prestressing cables; another unique feature of this design is that the path of a hole is that of a great circle.

A strong interest has developed in the use of smaller segments for fabricating prestressed ceramic domes. At present, a method developed by Meyer and Bellifante[2] is being studied, with the intent of designing several small triangular segments which may be used to generate a dome. This design also will require the design of the network of prestressing cables.

2. Fabrication Methods

Several fabrication methods were tried, in anticipation of their use in making segments of the type shown in Figure 2, or smaller.

a. Slip-casting a single hemispherical element: While the element was still soft, it was cut with a knife into triangular segments. The segments so formed were to be dried and fired. This method proved difficult.

b. Plastic-forming individual triangular elements: A plastic mixture of the body was rammed into a mold shaped to form elements of the type of Figure 2. After drying, the element was removed from the mold and fired.

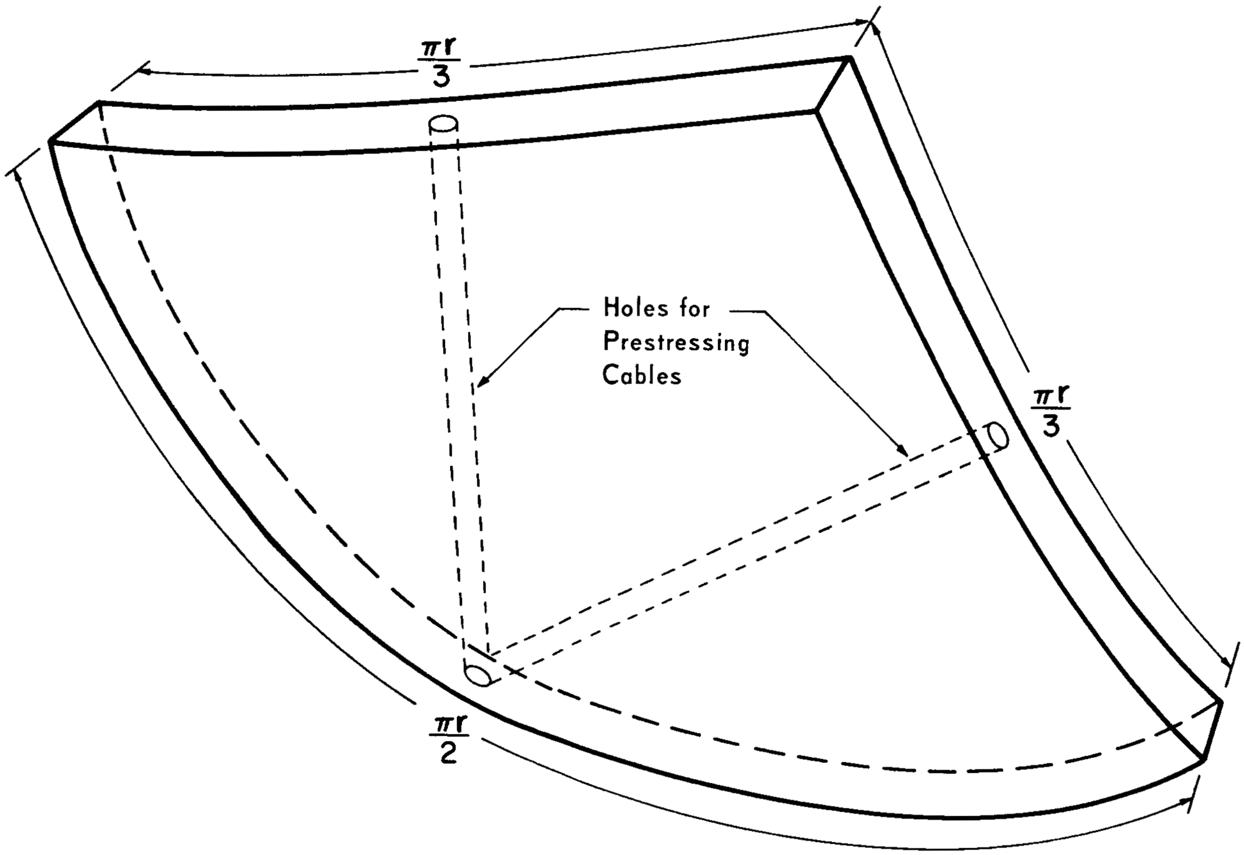

Figure 2

Triangular Segment for Fabricating a Hemispherical Dome

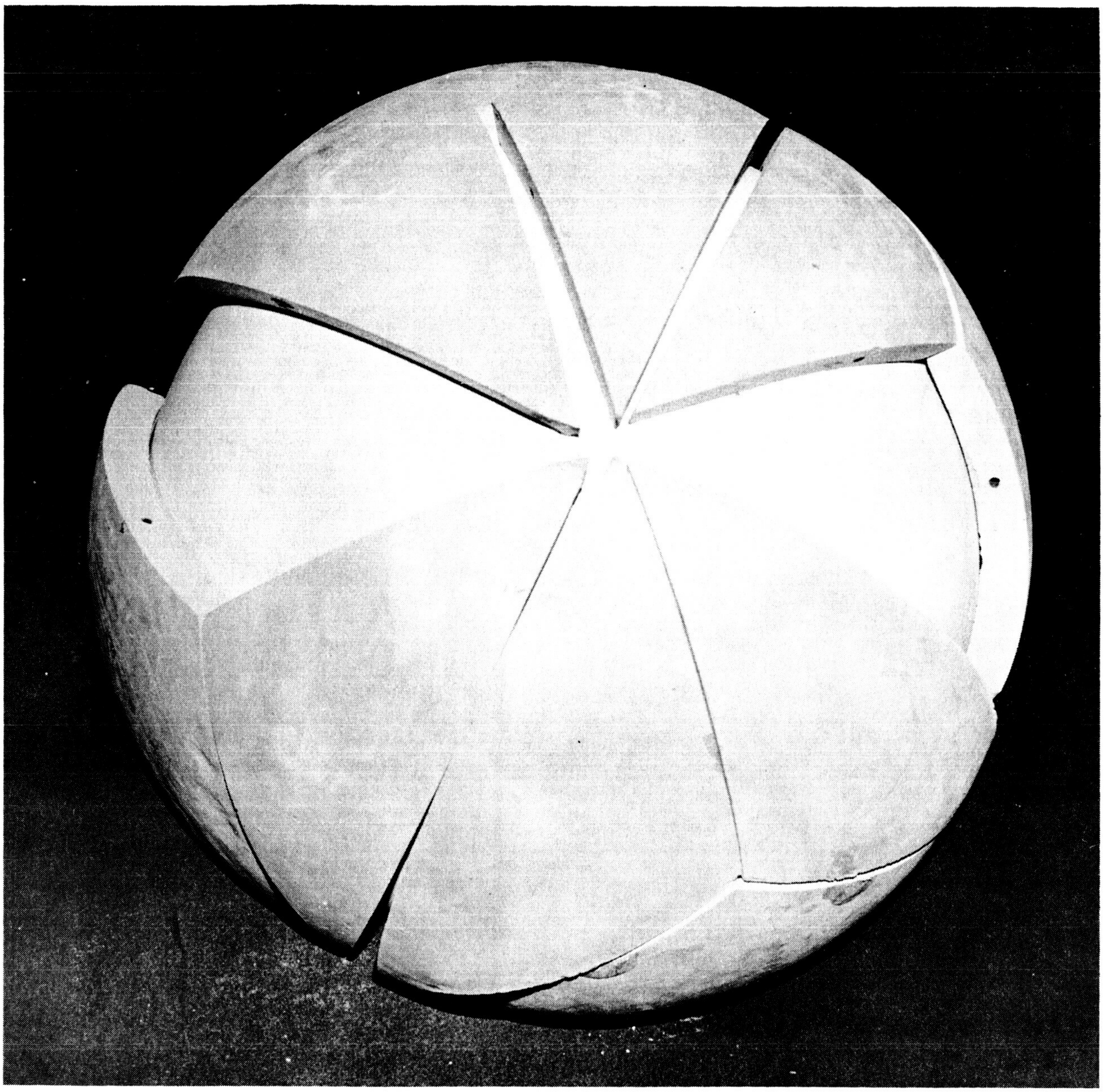

Figure 3

Triangular Segments

a. Ramming a ceramic body into a preformed refractory metal "honeycomb": This is a method used by the Boeing Company to fabricate the refractory nose-cap for an aerospace vehicle. Our experimentation involved the fabrication of a hemispherical dome by ramming an air-setting material into the meshes of a preformed metal (aluminum alloy in this trial) honeycomb. The shape of the individual segment was not significant in this experiment, but was chosen because of the availability and easy-forming character of the honeycomb material (see Figure 4). It is intended that the metal honeycomb function as gasketing between the segments.

To summarize the results of experiments with fabrication methods, it would seem feasible to use either slip-casting or plastic-forming for forming individual segments. However, it was clear that shrinkages occurring in drying and firing make it difficult to maintain close size tolerances and shape. Undoubtedly grinding of the fired segments would be required in order to produce good fitting and well-mated surfaces. The ramming of a ceramic material into a preformed honeycomb is an attractive method for forming and assembling small segments.

As a final observation, it is difficult to successfully manufacture closely-sized segments (for generating elements with double curvature) with the limited facilities and staff of a university laboratory. Such a fabrication task may be accomplished most successfully by a manufacturer of technical ceramics.

6. Behavior of Biaxially Prestressed Ceramic Plates Subjected to Thermal Stresses

The use of biaxial prestressing as a means of reducing or preventing damage to ceramic specimens under thermal stress was studied. The extent of structural damage of the ceramic material, after thermal stressing, was evaluated by determining the degradation in its bending strength. The experimental results indicated that the residual bending strength of the thermally stressed plates increased linearly with increasing levels of precompression, until a level of prestress was reached which was equal to the bending strength of the virgin material. Prestress levels of this value, or greater, for the conditions of this experimentation, appeared to provide full protection against damage under the imposed thermal load.

A paper based upon this work has been written, and copies will be transmitted at an early date to the NASA.

7. Load-Bearing Characteristics of Uniaxially Prestressed Beams

A program has been started to measure the deflection and fracture strength of uniaxially prestressed ceramic beams. In the case of a beam, equations derived in a previous work[3] are being carefully evaluated with the present data.

The ceramic beams were cut to 3/8" x 1/2" x 4" in size with a diamond saw. Four point loading was employed to load the beams to fracture in an Instron universal testing machine while the beams were subjected to various levels of prestress. (The prestressing fixture used is shown in Figure 5).

All the experimental work has been completed and the results are being critically evaluated. A report on this study will be prepared in the near future.

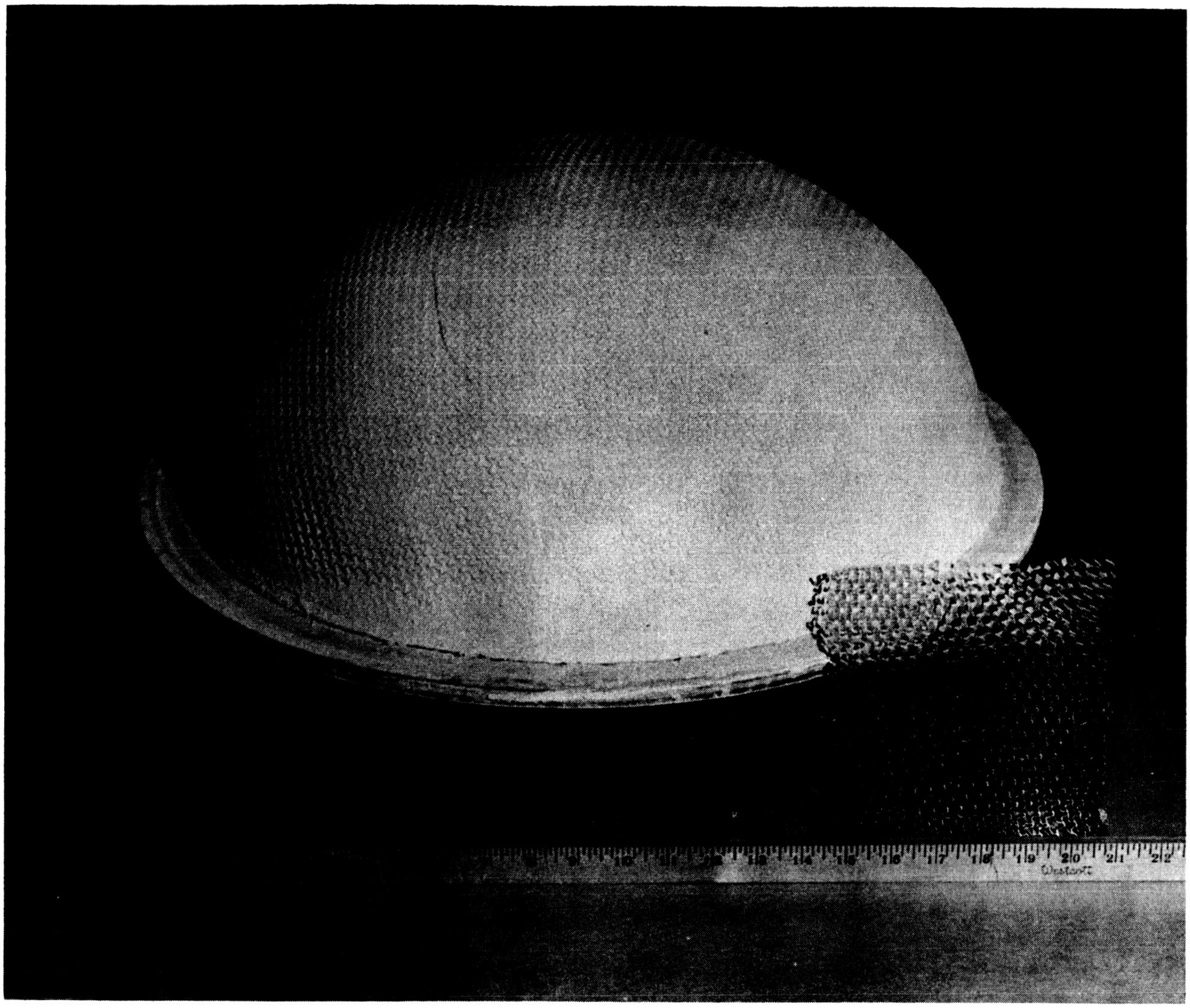

Figure 4

Hemispherical Dome Fabricated by Ramming a Ceramic Material in the Meshes of a Metal Honeycomb

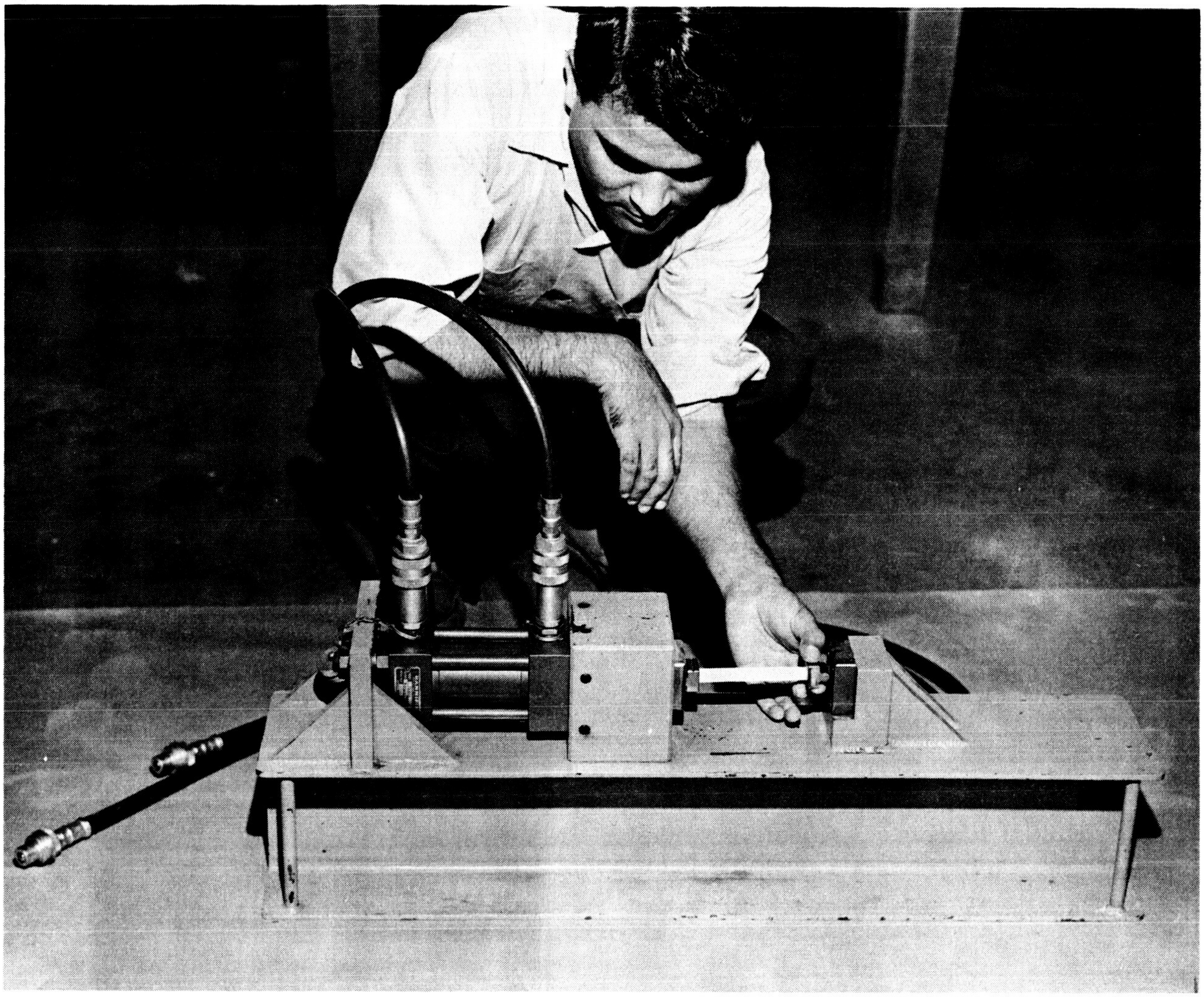

Figure 5

Fixture Used for Uniaxial Prestress Loadings

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[1]S. H. Brand, "Analysis and Design Considerations of Underwater Ceramic Capsules," M.S. Thesis, University of California, Los Angeles, June 1965.

[2]R. R. Meyer and R. J. Bellifante, "Fabrication and Experimental Evaluation of Common Domes Having Waffle-like Stiffening," Douglas Report SM-47742, November 1964. Submitted under NASA Contract, NAS 8-11542.

[3]Ali, Chipman, Knapp and Kurtz, "Load-bearing Characteristics of Biaxially Prestressed Ceramic Plates," NASA CR-188, 1965.